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REVIEW OF DEVELOPMENT OF SOME NEW TYPES OF GYROES

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19970206 077

**HUMAN TRANSLATION**

NAIC-ID(RS)T-0305-96 25 November 1996

MICROFICHE NR:

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English pages: 12

Source: Cama, China Astronautics and Missilery Abstracts,  
Vol. 3, Nr. 1, 1996 (Journal of Uest of China,  
Vol 21, Nr. 5, October 1995); pp. 485-489.

Country of origin: China

Translated by: SCITRAN  
F33657-84-D-0165

Requester: NAIC/TASC/Richard A. Peden, Jr.

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REVIEW OF DEVELOPMENT OF SOME NEW TYPES OF GYROES

Xue Wensheng

Translation of "Qian Xi Ji Zhong Xin Xing Tuo Luo De Fan Zhan Dong Tai"; Journal of UEST of China, Vol.24, No.5, October 1995, pp 485-489

**ABSTRACT** Beginning from fiber optic gyroscopes, hemispheric HRG gyroscopes, and laser gyroscopes, a simple introduction is made of the development trends associated with these several types of gyroscopes and some new progress associated with microelectronic technology. The introduction of micropackaged technology into gyroscopic information processing is put forward--causing the conversion of circuits to microelectronics, modularization, and conversion to packages. In conjunction with this, a suggestion is put forward for vigorous development of fully integrated fiber optic gyroscopes.

**KEY WORDS** Gyroscope Development Micropackage technology Tendency

CHINESE BIBLIOGRAPHICAL CLASSIFICATION V241.5

Due to the fact that gyroscopes--in any environment--all possess autonomous navigational capabilities, in recent years, despite the fact that the development of GPS caused inertial navigation systems to be subjected to a shock, GPS, however, is not capable of replacing inertial systems. In some application realms, it is still necessary for them to supplement each other. In some application realms--due to the development of GPS--the development of inertial systems has, on the contrary, been promoted. At the present time, the focus in the development of inertial instruments is solid state inertial sensors. Among these, fiber optic gyroscopes, laser gyroscopes, and hemispheric gyroscopes attract the most attention from people. Microelectronic technology acts as today's leading technology--in the midst of entering, step by step, into inertial systems--and will cause information processing circuits to gradually convert to microelectronics, modularization, and conversion to subassemblies.

# 1 DEFINITION OF GYROSCOPE AND OUTLINE OF DEVELOPMENT

A gyroscope is a type of internal sensor which, even if there are no external reference signals, is still capable of detecting changes in the attitude status of platform bodies themselves. The function of gyroscopes is to sense the angle, angular velocity, and angular acceleration of moving bodies. Making use of the fixed axial nature and precession characteristics of gyroscopes, it is

possible to measure the attitude angles (course, pitch, roll) of moving bodies, to precisely measure the angular movements of moving bodies, and, through inertial coordinate systems composed in association with gyroscopes, to realize stable inertial platforms.

Gyroscopes already have a development history of more than 100 years. In 1910, a north pointing gyrocompass carried on ships was produced for use for the first time. The development process can be roughly divided into four phases. The first phase was the gyroscope associated with ball bearing supported gyroscope motors and frames. The second phase was liquid floated and gas floated gyroscopes which were developed at the end of the 1940's and the beginning of the 1950's. The third phase was rotor gyroscopes associated with rod type dynamically flexible supports. At the present time, the development of gyroscopes has already entered into the fourth phase, that is, electrostatic gyroscopes, laser gyroscopes, fiber optic gyroscopes, and oscillating gyroscopes.

Performance to cost ratios associated with different types of gyroscopes are different. Moreover, as far as different realms of applications such as weapons, warships, missiles, aircraft, as well as robots, and so on are concerned, requirements associated with performance cost ratios for gyroscopes are also not the same. Up to now, many types of gyroscopes have already achieved broad applications in different realms. As a result, we are only able to say that the appearance of one type of new model gyroscope compensates for the shortcomings associated with certain types of gyroscopes that are already on hand, thereby satisfying the requirements of a certain realm of application. It is, however, not possible to say that the appearance of a certain type of gyroscope replaces other gyroscopes.

## 2 FIBER OPTIC GYROSCOPES

Fiber optic gyroscopes are composed of such basic components as light sources, electro-optical modulators, fiber optic coils, as well as optical detectors, and so on. The light coming out of optical sources is projected on electro-optical modulators. One light beam is divided into two light beams. After that, they respectively couple into fiber optic coils from the two ends of the optical fiber coils. After going through fiber optic coils in opposite directions, they are, respectively, shot out from their ends. As far as the light coming out of the two ends of the fiber optic coils is concerned, it again goes through electro-optical modulators, being combined once more. In conjunction with this, interference is produced. When fiber optic coils are placed in a stationary configuration, the phase difference associated with the two light beams coming out of the two ends of fiber optic coils is zero. When fiber optic coils turn with an angular velocity of  $\omega$ , the phase difference produced between the two beams because of

Sagnac effects is

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$$\Delta\Phi_s = 4\pi LR\omega / \lambda C$$

In the equation, L is the fiber optic length. R is the radius of the fiber optic coil.  $\lambda$  is the optical wave length. C is the speed of light. The combined light beams are thrown onto optical detectors, detecting the interference variations given rise to by changes in angular rotation velocities  $\omega$ , thereby acquiring information associated with angular velocity  $\omega$ .

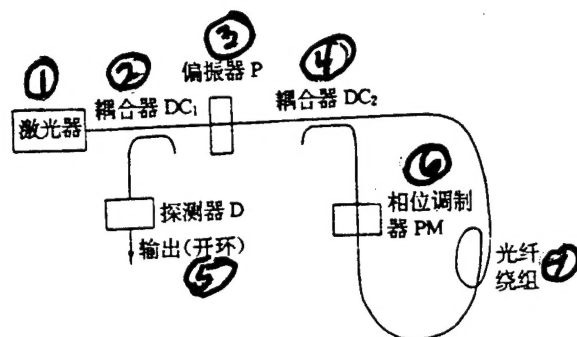


Fig.1 Diagram of Principles Associated with Full Fiber Optic Gyroscopes

Key: (1) Laser (2) Coupler  $DC_1$  (3) Polarization Device P (4) Coupler  $DC_2$  (5) Detector D Output (Open Loop) (6) Phase Modulator PM (7) Fiber Optic Winding

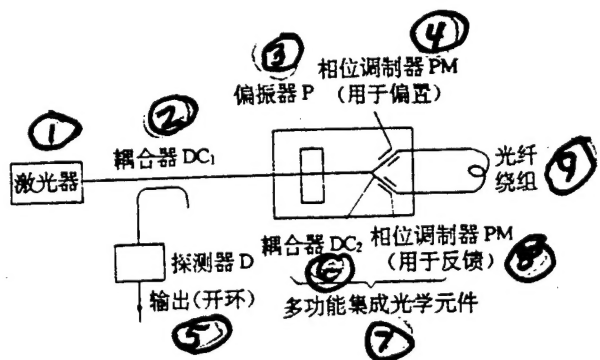


Fig.2 Diagram of Principles Associated with Integrated Fiber Optic Gyroscopes

Key: (1) Laser (2) Coupler  $DC_1$  (3) Polarization Device P (4) Phase Modulator PM (Used in Offset) (5) Detector D Output (Open Loop) (6) Coupler  $DC_2$  (7) Multiple Function Integrated Optical Components (8) Phase Modulator PM (Used in Feedback) (9) Fiber Optic Winding

At the present time, fiber optic gyroscope development is divided into two types--fully fiber optic gyroscopes (see Fig.1) and integrated fiber optic gyroscopes (see Fig.2). Full fiber optic gyroscopes are fiber optic gyroscopes that make use of fiber optic couplers, fiber optic polarization devices, and so on. Integrated

fiber optic gyroscopes take couplers, polarization devices, as well as phase modulators and integrate them onto one electro-optic crystal.

Advantages of fiber optic gyroscopes include the following. 1) High sensitivity and low detection threshold. The lowest angular velocities which fiber optic gyroscopes are capable of detecting are  $0.0078^\circ/\text{h}$ . 2) Fiber optic gyroscopes are a type of solid state gyroscope. Shock resistance and vibration resistance properties are good. 3) Fiber optic gyroscopes do not have lock up phenomena during low rotation speeds. 4) Responses associated with fiber optic gyroscopes possess high linearity and large dynamic ranges. 5) They are capable of making use of integrated optics technology to realize optical integration, to lower costs, and to improve reliability.

The primary drawback associated with fiber optic gyroscopes is that capabilities for resisting nuclear radiation are comparatively bad.

At the present time, internationally, the development of fiber optic gyroscopes is rapid. In military terms, the three U.S. services helped ten large U.S. companies begin comprehensive research on fiber optic gyroscope development in the early 1980's. Among these, the most representative were the Litton and Honeywell companies. The Litton company began production of small batches of Litton 200 model fiber optic gyroscopes in 1992. Drift is  $0.01^\circ/\text{h}$ , achieving the levels of inertial guidance. The next objective is--using a period of 3-5 years--to make fiber optic gyroscope drift reach  $0.003^\circ/\text{h}$ . In 1990, the U.S. military fiber optic gyroscope market was 188 million U.S. dollars. The 1994 forecast was for 1.2 billion U.S. dollars.

In terms of civilian uses, in 1984, the McDonnell-Douglas company put out for the first time a batch of operational fiber optic gyroscopes. Precision was  $10^\circ/\text{h}$ . They were used in petroleum drilling rigs. The former West Germany's Luolunzi (phonetic) standard electrical apparatus company plans, within a few years, to fit 1/4 of Germany's currently existing 4 million motor vehicles with low accuracy fiber optic gyroscopes. As far as Japan is concerned, the Sinyu electrical equipment company is typical. In the development of low accuracy fiber optic gyroscopes, use has already been made of fiber optic gyroscopes to manufacture land vehicle guidance systems. With regard to vehicles driving at 120km/h speeds, deviation is 1m per kilometer. The navigation system on the 777 civilian airliner, which the U.S. Boeing company has recently put out, makes use of high precision fiber optic gyroscopes.

Beginning in the early 1980's, China started to carry out development of fiber optic gyroscopes. There were a number of research institutes and universities engaged in studies associated with this area. Up to the present time, development of experimental prototypes has been completed. The main difficulty currently being met with is not having good components--for example, optical fiber, super radiation light emitting diodes, detectors, optical integrated chips, fiber optic coils, and so on--



blocking development progress on fiber optic gyroscopes to a very great extent. Based on these causes, we must make use of the advantages of combined domestic technologies, taking as a point of departure the development of good components, making the most of a spirit of vigorous cooperation, and combining to attack the key problems associated with joint development of fiber optic gyroscopes. Pulling together research units from those already possessing comparatively strong overall capabilities, strength was concentrated in the development of optical fiber that guarantees polarization, monocrystalline  $\text{LiNbO}_3$ , as well as integrated optical circuitry chips with the expectation of being capable of use in near term development of fully integrated optical fiber optic gyroscopes. /486

### 3 HEMISPHERIC HRG GYROSCOPES

In 1890, the British physicist G.H. Bryan discovered thin walled resonators possessing the shapes of revolving bodies are capable of sensing rotation characteristics. This is nothing else than the foundation theory for hemispheric resonance gyroscopes. Hemispheric resonance gyroscopes (see Fig.3) are primarily composed of resonators, drive device shells, and casings carrying sensor read outs. Mechanical sections are constructed from 3 hemispherical structural bodies made from fused quartz material. Intermediate hemispheric oscillators produce vibrations under electrostatic excitation associated with outside hemispheres. Vibrations form standing waves on hemispherical oscillators. There are 4 nodal points. When there are angular velocity signals transmitted into the direction of sensing axes associated with hemispherical oscillators, the positions of these 4 nodal points will then give rise to changes. Making use of other parts--that is, electrical capacitance sensors on interior hemispheres as well as related electronic circuitry--the changes in nodal points are measured. It is then possible to measure displacement signals associated with angles of rotation.

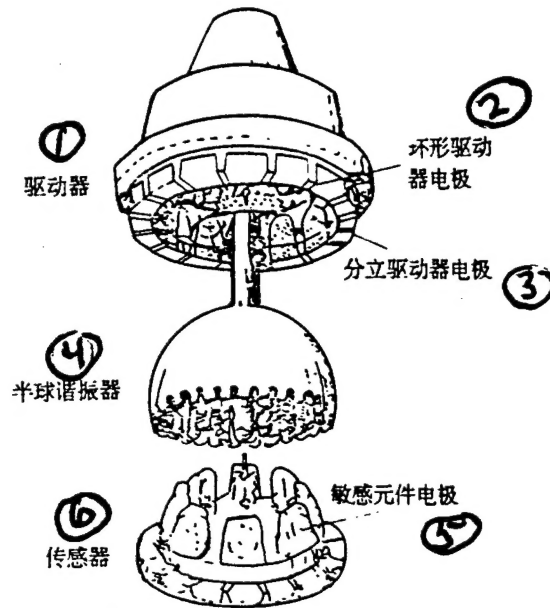


Fig.3 Diagram of Principles Associated with Hemispherical Resonance Gyroscopes

Key: (1) Driving Device (2) Ring Shaped Driving Device Electrode (3) Independent Driving Device Electrode (4) Hemispherical Resonator (5) Sensor Component Electrode (6) Sensor

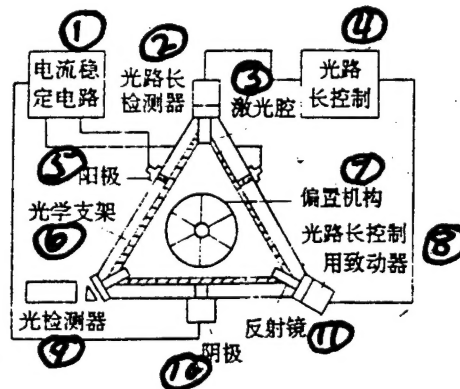


Fig.4 Diagram of Principles Associated with Laser Gyroscopes

Key: (1) Current Stabilizing Circuitry (2) Light Path Length Detector (3) Laser Cavity (4) Light Path Length Control (5) Anode (6) Optical Frame (7) Offset Mechanism (8) Movement Initiating Device Used to Control Light Path Length (9) Light Detector (10) Cathode (11) Reflector

The advantages associated with hemispheric resonance gyroscopes are as follows. 1) There are no mechanical structures subject to wear or moving parts. Reliability is high (MTBF at  $15 \times 10^4$  or higher). Life is long (20 years). Resistance to shock is high (500g). 2) There is no need for temperature control systems. It is possible to operate within a range of  $-54$  --  $+105^\circ\text{C}$ . 3) With an interrupted supply of electricity, it is still possible to operate (up to 30 min). Possesses capabilities to get through nuclear interference. 4) Electrical supply is simple. Power consumption is small. Operating start up times are very fast (a few seconds). 5) Not susceptible to magnetic fields. Counter electronic interference capabilities are strong. 6) Precisions are high. It is possible to sense the spin of the earth.

At the present time, the U.S. holds the leading position in the area of the development of hemispheric gyroscopes. They have two large classes of high and medium precisions, that is, strategic and tactical models of product. Among these, high precision product random drifts already exceed  $0.001^\circ/\text{h}$ . The annual production of quick connect inertial guidance systems already exceeds 500 sets. Production value is as much as hundreds of millions of U.S. dollars. These products are already successfully used in quick connect inertial guidance systems associated with many types of aircraft, precision guidance systems of delivery means, and intercontinental ballistic missile precision quick connect guidance systems. In conjunction with this, in 1989, an investment by the military of 3.9 million U.S. dollars expanded them to use in intermediate range missiles. Russian hemispheric resonance gyroscope random drifts are already smaller than  $0.01^\circ/\text{h}$ . In conjunction with that, as far as the construction of quick connect inertial guidance systems is concerned, horizontal random drifts under study are already smaller than  $0.001^\circ/\text{h}$ . With regard to Chinese hemispheric resonance gyroscopes, hemispheric gyroscope prototypes with random drifts of  $0.1^\circ/\text{h}$  have already been developed.

#### 4 LASER GYROSCOPES

A type of typical laser gyroscope product is a ring shaped laser gyroscope. The principles are seen in Fig.4. The light path is an optical circuit with a triangular shape dug through pieces of fused quartz. The laser medium is He-Ne. The laser wave length is  $632.8\text{nm}$ . It is possible to verify that, when ring shaped laser gyroscopes use angular velocities of rotation  $\omega$ , because of Sagnac effects, it makes oscillation frequencies associated with the two light beams propagated along opposite directions in them different. Beat frequencies observed in optical detectors are

$$\Delta f = 4A\omega / \lambda L$$

In the equation, A is the area surrounded by light beams. L is the light path length associated with ring shaped resonators.  $\lambda$  is oscillation wave length when stationary. From the equation above,

it can be seen that, so long as beat frequencies  $\Delta f$  are measured (illegible), it is then possible to precisely specify angular velocities corresponding to inertial space. /488

The advantages associated with laser gyroscopes are as follows. 1) They possess large dynamic ranges and high velocity performance. 2) Precisions are high. 3) Start up times are fast. 4) Counter environmental interference characteristics are good. 5) Reliability is high.

The drawbacks associated with laser gyroscopes are as follows. 1) There exist lock up phenomena. That is, in low angular velocity regions, frequency drag is produced, causing beat frequencies to be zero and not being able to detect angular velocities of rotation. 2) Prices are high due to the fact that manufacturing techniques are complicated and materials are expensive. 3) Volumes are comparatively large and cannot be reduced, being subject to the sensitivity requirements.

Internationally, the level of laser gyroscopes developed by the U.S. Honeywell company is the highest. It produces 200 laser gyroscopes a month. These are primarily used in the inertial guidance systems of Boeing 757 and 767 passenger planes. Laser gyroscopes developed by the Litton company are primarily used in large model, long range and short range European passenger planes as well as long range, close range and short range missiles. In the realm of high performance inertial guidance, at the present time, other gyroscopes still have difficulty competing with laser gyroscopes.

Domestic development of laser gyroscopes began in the early 1970's. Going through close to 20 years of effort, experimental laser gyroscope prototypes have already been produced.

## 5 DIRECTIONS OF DOMESTIC DEVELOPMENT

Above, we have already been respectively introduced to the status of development of fiber optic gyroscopes, hemispheric gyroscopes, and laser gyroscopes. Based on the overall level of technological strength in China at the present time, in order to make the fruits of scientific research turn as fast as possible to practical uses, to develop as quickly as possible gyroscope components of a high level, and to satisfy the demands of the market, the development directions which should be adopted are as follows.

1) In terms of the selection of gyroscopes, the development of fiber optic gyroscopes is the main thing. Comparing in a comprehensive way fiber optic gyroscopes, hemispheric gyroscopes, and laser gyroscopes--despite the fact that fiber optic gyroscopes cannot compare in certain areas with the other two types of gyroscopes--in the realms of application associated with medium and low precision inertial systems, however, fiber optic gyroscopes have such advantages as being simple in their manufacturing techniques and high performance cost ratios--possessing comparatively strong competitive advantages. Among gyroscope instruments made use of in inertial navigation level systems, fiber

optic gyroscopes also display their competitive advantages. Looking in terms of the development of fiber optic gyroscopes, the ones possessing the most vitality are fully integrated fiber optic gyroscopes. The reason is that they opt for the use of optical integration techniques, are capable of realizing large scale production, low costs, and, in conjunction with that, are able to improve the properties associated with fiber optic gyroscopes. In order to accelerate the pace of development, first of all, aim should be taken on the civilian market--developing medium and low precision gyroscopes to satisfy such needs as those associated with petroleum well drilling, motor vehicles, and so on, using this to drive the development of fiber optic gyroscopes.

2) As far as making breakthroughs in and mastering production technologies associated with polarization preserved fiber optics is concerned, the properties of fiber optic gyroscopes--in particular, costs--are greatly dependent on polarization preserved fiber optics. Looking at the domestic situation at the present time, the key technologies associated with polarization preserved fiber optics have already had some breakthroughs. Among these are two types of polarization preserved fiber optics associated with comparatively high levels--the Panda model and the Internal Rule model--possessing foundations for conversion to production technologies. Through concentrating strength to help sustain units which are making relatively fast progress in developing polarization preserved fiber optics, it is possible to very quickly achieve results. Internationally, polarization preserved fiber optics can still only be produced by a small number of nations. It is a high technology product. The prices associated with polarization preserved fiber optics are very expensive. The market is also very large. As a result, we should seize this opportunity, taking full advantage of the cheap cost of domestic labor and technological advantages, completing as fast as possible the conversion of developed polarization preserved fiber optics into production technologies, satisfying domestic requirements, and, in conjunction with that, exporting and capturing the market and accumulating funds.

3) Beginning with the key components used in the development of fiber optic gyroscopes, develop operational devices which are both capable of production in large lots and, in conjunction with that, able to satisfy uses associated with fiber optic gyroscopes--for example, super radiation light emitting diodes, optical integrated circuitry chips, optical detectors, fiber optic coils, and so on. This primarily depends on the efforts of basic units possessing photoelectronic technology and industrial processing capabilities.

4) Develop the set of technologies associated with fiber optic gyroscopes--technical research associated with a conversion to microelectronics in information processing circuits. Information processing circuitry is an important constituent part of fiber optic gyroscopes. Their size directly influences the volumes and weights associated with fiber optic gyroscopes. In order to reduce the volumes and weights, improve reliability, and



facilitate maintenance and repair, micropackage technologies should be introduced--miniaturizing, modularizing, and converting circuitry to subassemblies.

The advantages associated with the domestic development of integrated fiber optic laser products lie in the following.

1) With regard to polarization preserved fiber optics, units engaged in research in this area include several research institutes. At the present time, they are already capable of supplying a number of sample items provided for research use. Among these, there are the Panda model and Internal Rule model of polarization preserved fiber optics, which are of the highest level. In accordance with the pace at the present time, it is possible to very quickly develop and, in conjunction with that, be able to produce operational polarization preserved fiber optics.

2) As far as key components used in regard to fiber optic gyroscopes are concerned--integrated circuitry chips, super radiation light emitting diodes, detectors, and so on--at the present time, it is already possible to produce sample items for use in research. Through vigorous efforts, it is possible to very rapidly convert them to practical use.

3) With regard to the conversion of processing circuitry to microelectronics, at the present time, we are just in the midst of a high tide domestically associated with research on multiple chip module (MCM) technology. Technological levels are improving very fast, causing, with respect to circuitry, a development toward modularization and conversion to subassemblies. Volumes and weights are constantly reduced, and, in conjunction with that, the reliabilities of systems are made to very, very greatly improve, at the same time, very, very greatly simplifying maintenance procedures. /489

Up to the present time, technologies which have already been mastered and are comparatively mature include the following.

1) Technology associated with the conversion of components to chips--for example, chip type electrical resistance networks, electrical capacitance, electrical inductance, capacitance inductance networks, potentiometers, voltage transformers, and so on are capable of satisfying requirements.

2) Micropackage design technology--including substrate modularization thermal design technology, CAD wiring technology, and so forth. High heat ceramic substrates are capable of realizing multiple layer wiring. Thin film circuitry is capable of realizing multiple layer wiring. Thick films are capable of realizing multiple layer wiring.

3) As far as micropackage substrate technology is concerned, low heat ceramic substrates are capable of achieving multiple layers. High heat ceramic substrates are capable of achieving multiple layers. Thick film multiple layer substrates are capable of being made in multiple layers. Thin film technologies are capable of achieving multiple layers. Mixed thin and thick film technologies are capable of being made in multiple layers.

4) With regard to micropackage sealed technology, it is capable of realizing various forms of seals such

as LCCC (ceramic seal without lead), PGA (pin grouping array seal), QFP (quadrilateral flat lead seal), TAB (carrier belt automatic welding), and so on.

Besides this, there has also been development of research associated with such new technologies as silicon based multiple layer wiring, as well as button welding, and so forth. As a result, basic capabilities for the development and production of multiple chip module technologies and industrial technology equipment already exist in a preliminary way. It is possible to develop and produce modularized circuitry products aimed at the needs of different users, making circuitry constantly miniaturize, modularize, and convert to subassembly packages in order to satisfy the needs of systems as a whole.

If we are able to very rapidly realize fiber optic gyroscopes and enter into the practical utilization of this objective, on the one hand, it is possible to drive in a very good way the level and pace of domestic gyroscope development. On the other hand, it is also possible to accumulate previously researched results, altering results which were developed but not produced in the past in predicaments which made conversion to practical uses difficult.

In summary, in situations where funds are limited and there are many types of requirements, we should, first of all--on the basis of the concrete domestic situation--select projects which are capable of producing results very quickly, concentrate our investment strength, strive for an early outcome and the rapid production of results--at the same time, tracking international development directions and carrying out follow on research with regard to a number of high technologies.

Thanks go to Professor Cheng Shuqing, Professor Xiao Anqian, and Senior Engineer Wang Zheng for their guidance with regard to this article.

#### REFERENCES

- 1 Galloreni T G. Optical-fibre sensors challenge the competition IEEE SPECTRUM, 1986, 23(9): 44~49
- 2 Gubbins H L. A prototype strapdown IRU with passive Fibre Optic Gyros. NEACON, 1987, 2: 376~382
- 3 高希才. 光纤陀螺的发展趋势. 压电与声光, 1988, 10(6): 23~27